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Remote Sensing of Natural Areas: Procedures and Considerations for Assessing Stress and Pollution

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Introduction

Remote sensing can be defined as the “acquisition and measurement of data/information on some property(ies) of a phenomenon, object, or material by a recording device not in physical, intimate contact with the feature(s) under surveillance” (Short 1997). Scientists employing remote sensing are able to collect vast quantities of data quickly and efficiently for rapid analysis. One potential use of remote sensing is in the assessment and management of natural areas. Remote sensing in this field has focused on the spectral and spatial properties of vegetation and the surrounding landscape. Changes in these characteristics can be measured over time to aid in understanding what is occurring in a desired area. The data collected, and the sensors used to collect it, depends primarily on the user’s purpose for the data. Features of the environment will also help determine which equipment is the most ideal for a given project. In this discussion, we will examine the use of remote sensing in evaluating vegetation stress and pollution in wetlands.

Vegetation Stress

Stress and the EMS

Stress has been defined as “any environmental factor capable of inducing a potentially injurious strain on a plant” (Murtha 1982). A strain is “any physical or chemical change in a plant produced by stress” (Murtha 1982). Stress can manifest itself as many strains, and may be morphological (e.g., affecting vegetation shape or

form) or physiological (e.g., affecting vegetation function). Some changes, such as seasonal changes, are normal. The detection of stress relies on being able to determine and detect the deviations from normal function (Murtha 1982). After one understands what is considered normal, or average, for a plant, one can then look for and identify strains, i.e. differences from the normal or average conditions, which may signal stress.

Remote sensing equipment is able to detect changes in vegetation spectral reflectance caused by stress. Spectral reflectance is the energy in the electromagnetic spectrum (EMS) reflected from an object of interest, expressed as a percentage of the incident radiation through a range of wavelengths (Carter 1991). Most of the energy given off by the sun is in the visible and near-infrared wavelength range. As a result, most remote sensing of vegetation uses those wavelengths.

An example of the data used to analyze stress, in the form of a *spectrograph*, is shown in Figure 1 (page 2). The spectrograph shows how much light is reflected at different wavelengths, ranging from blue light to the near infrared. For example, plants appear green to us because they reflect more green light (at 550 nm) than blue (450 nm) or red (650 nm). Different species look different to us because of how they respond to light. The high reflectance at the far right is caused by reflection of infrared energy and is due to the structure of the plant itself. If infrared was a color that we could see, all vegetation would appear to be the ‘color’ infrared rather than green.

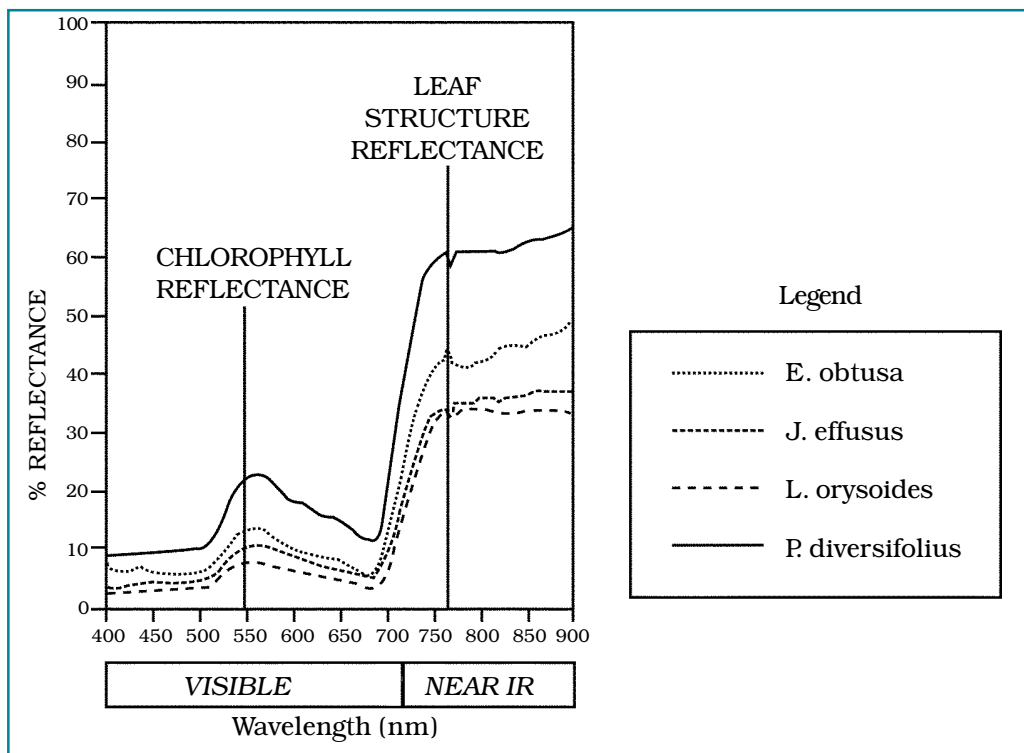


Figure 1. Spectrographs provide one means of viewing remotely sensed data (from Anderson and Perry 1996).

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Commonwealth's Declared Policy: "to preserve the wetlands and to prevent their despoliation and destruction..."

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The Appearance of Stress

While spectral reflectance depends on such factors as available light, species, site, maturity, nutrient status, and leaf orientation of vegetation, one of the first general visual symptoms of physiological injury is vegetation yellowing, or chlorosis (Murtha 1992). However, depending on the nature of the stress and its effect on the plant's chemistry, changes may occur in the infrared (IR) wavelengths before the visible spectrum (Murtha 1992). In other words, chlorosis may appear after other changes appear that are not visible to the naked eye. If a stress is manifested as a change in water concentration (turgor pressure) of a plant, typically the IR wavelengths will change before the visible in a plant's spectral signature. A person equipped with a sensor able to see those wavelengths could detect and respond to a stress much faster than someone without the proper equipment. As water is lost from a leaf, reflectance increases in the short-wave IR region (Carter 1991). A survey to detect stress in a representative portion of an ecosystem could be easily accomplished by using a spectroradiometer, a hyperspectral non-imaging sensor that collects data across the EMS in discrete intervals. The ground readings could be compared to readings from similar locations or previous data from the area to determine the effects of stress (Murtha 1982).

Remotely Sensing Stress

There are several factors that must be considered when using remote sensing equipment to detect vegetation stress, such as planning a proper field survey and considering whether to use satellite or aerial imagery. The resolution needed is important and must be decided before undertaking a survey. As the scale increases, the detail and information in an image changes.

A general rule of thumb is to use the smallest scale possible to provide the desired level of detail. In this way, a larger area can be obtained as data, minimizing time required for data acquisition, interpretation, and analysis of separate images (Werth and Work 1991).

The film used in aerial photography and the sensors of satellites and digital multispectral video (DMSV), may be more sensitive to some regions of the

EMS than others. A true color photograph may not reflect the exact blend of blue, green, and red wavelengths actually present at the site because some films are more sensitive to particular wavelengths. Spectrally, the film emulsion, age, exposure, and processing technique need to be considered when examining photographic data (Murtha 1992). However, a desired study may only require broad classifications (Werth and Work 1991). In general, satellite data has a much smaller scale than that collected from an airplane. For smaller survey sites, or for areas where classification must be at the species level, aerial platforms are preferred.

The DMSV is an example of a sensor that uses multispectral videography. It is flown from an aerial platform and contains four cameras that can be fitted with the proper bandpass filters to receive four spectral images of the landscape. In this way, four discrete regions of the EMS can be collected for analysis. It is usually unnecessary to collect data from across a wide range of the EMS. With the proper knowledge of spectral

reflectance, required information about vegetation stress can be obtained by examining the spectral reflectance at specific wavelengths in an image (Carter and Miller 1994). For example, stress often causes an increase in the green spectrum (491-575 nm) near 550 nm and the red spectrum (647-760 nm) near 710 nm, with the effect on the red spectrum being greater than that on the green. The effects of dehydration on terrestrial plants occur most strongly in the yellow region of the spectrum (Carter 1993).

For wetland plants, stress causes increased reflectance in the visible spectrum since there is less chlorophyll available to collect photons provided by sunlight, and near IR (NIR) decreases due to cellular breakdown in the plant (Patience and Klemas 1993). Anderson and Perry (1996), working with the wetland species *Acer rubrum*, found increased reflectance levels at 550 and 770 nm and a shift in peaks to shorter wavelengths due to strains, such as chlorosis and cellular breakdown caused by flooding (Figure 2).

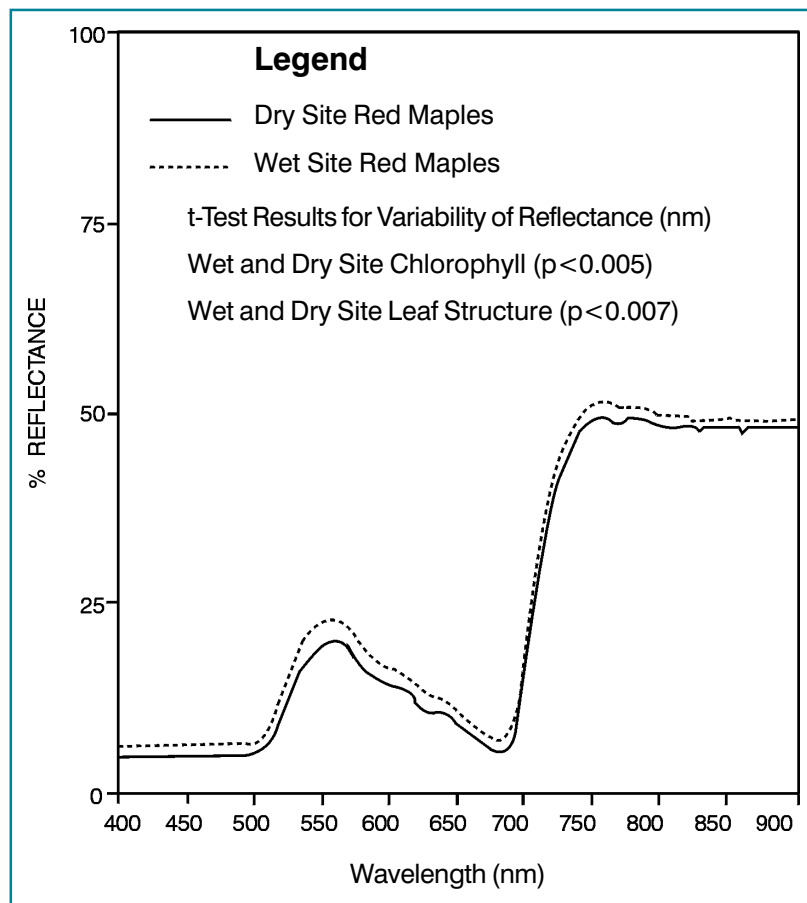


Figure 2. Average leaf spectral reflectance for *Acer rubrum* (L.) showing effects due to strain caused by flooding stress (Anderson and Perry 1996).

When collecting imagery data for analysis of vegetation stress, color IR data is preferred. Interaction with atmospheric particles causes the blue band of the EMS to be scattered more than other visible or IR frequencies. Many vegetation spectrographs demonstrate a rapid increase in reflectance as the wavelength changes from the red to the IR. The blue shift occurs when the red edge of this change, the slope, moves to shorter wavelengths. The observed change is often very slight, but present, for many kinds of stress. For example, Rock *et al.* (1988) found that a blue shift of 5 nm occurred in damaged spruce trees (Figure 3).

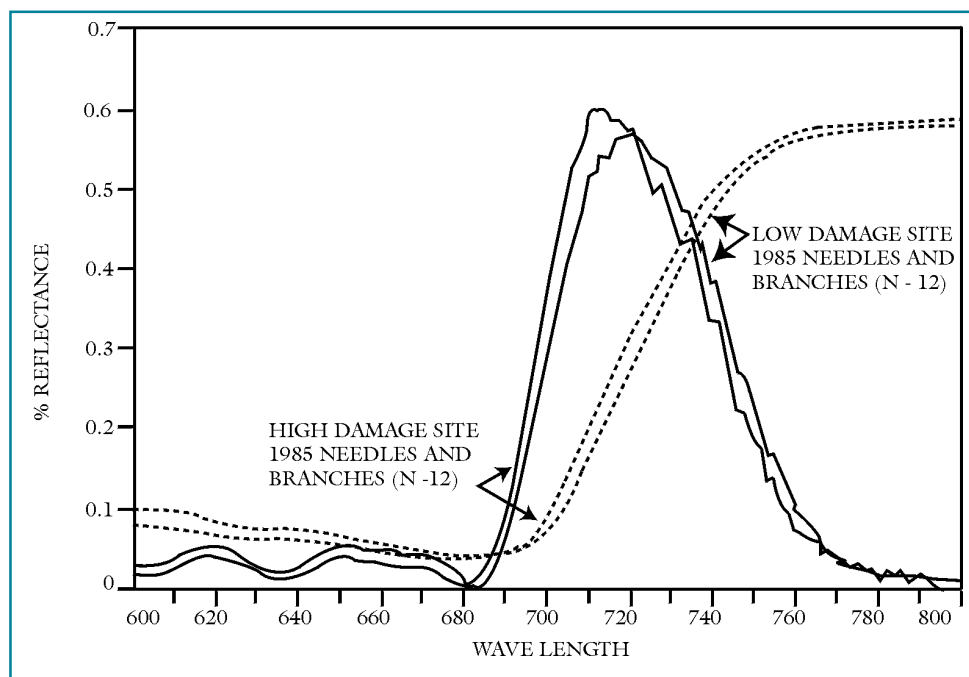


Figure 3. Comparison of averaged VIRIS reflectance curves (dashed lines) for plants from a high- and low-damaged site in Vermont. First derivative curves of each spectrum are presented as solid lines. Collected in June, 1985 (from Rock *et al.* 1993).

Biomass

Another technique used for evaluating wetland stress through remote sensing includes measuring biomass or net primary productivity. Patience and Klemas (1993) reviewed various indices, based on spectral reflectance data, which have been correlated with green biomass. The review reported that the indices were preferred over the use of single wavelengths for study because they compensated for short- and long-term changes in solar irradiance and atmospheric conditions (Patience and Klemas 1993). The index allows the interpreter to focus on the differences between wavelengths, rather than the pixel or image brightness, which is more variable (Lillesand and Kiefer 1994). One index, the vegetation index (VI) is equal to $[NIR - R] / [NIR + R]$. Another, the IR index (II), is equal to $[NIR - MIR] / [NIR + MIR]$. R, NIR, and MIR are meant to simulate bands 3-5 of the Landsat Thematic Mapper (Landsat TM), a satellite used to collect remotely sensed data from space. R represents the red portion of the EMS, the band sensitive to chlorophyll, from 630-690 nm. NIR, the near IR, is

the band sensitive to plant tissue structure from 760-900 nm. MIR, the middle IR, is the band most sensitive to water absorption in the EMS from 1550-1750 nm (Patience *et al.* 1993).

Summary

A study performed to detect wetland stress needs to consider bands chosen from the visible and IR wavelengths of the EMS. Color IR imagery is preferred to natural color imagery when examining the spectral reflectance of stressed vegetation. The choice between using a satellite or airborne platform should be selected based on the size of the survey site and the required resolution. If the user is looking for signs of stress in only a few trees, then a larger scale will be required than if the user was looking for signs of stress over a larger region. Vegetation indices should be used to help remove the effects of random factors. Narrow bandpasses should be selected within the available EMS to aid in analysis. If the bandwidth of a sensor is too large, features affecting specific parts of the EMS could be lost in the surrounding data. Finally, spectrophotometric verification should be done to correlate and confirm readings from the air or space.

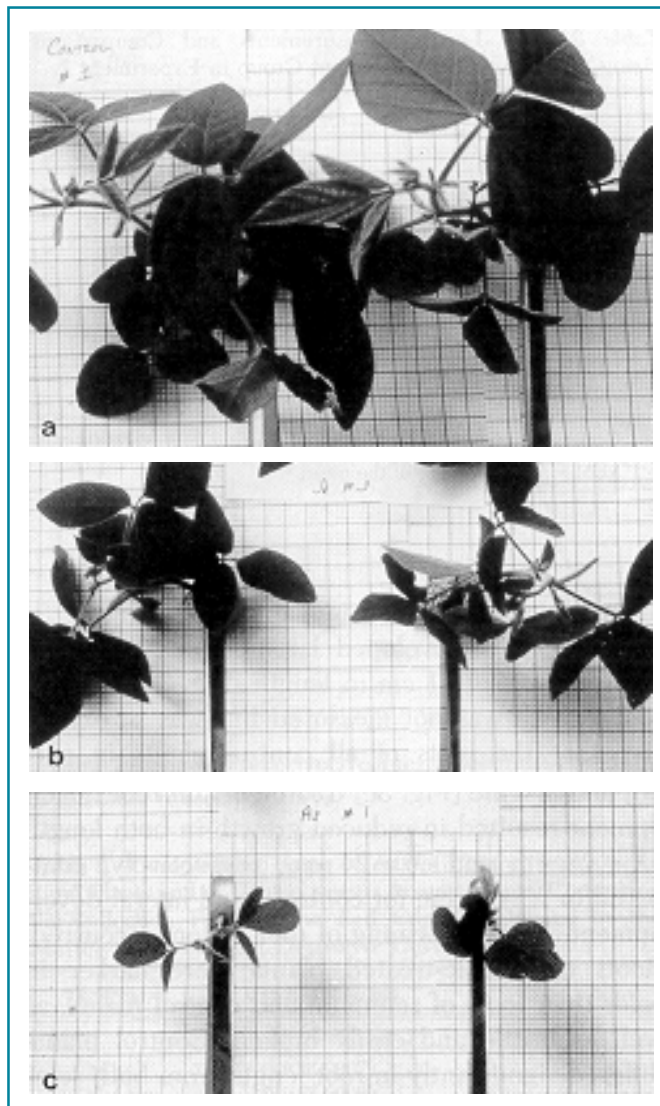


Figure 4. Soybean areal cover comparisons: a) control plants; b) selenium-dosed plants; and c) arsenic-dosed plants (from Milton *et al.* 1989).

Pollution

We can generally observe the effects of pollution on an ecosystem, not the pollutant itself. Therefore, pollution can be measured as a function of stress on vegetation. For example, we can not detect excess nutrients entering waterways as runoff using remote sensing. However, we can detect the increased spectral reflectance at 550 nm (green band) caused by algal blooms utilizing the nutrients as eutrophication sets in, or the increased spectral reflectance at 650 nm (red band) caused by red tide dinoflagellates.

Milton *et al.* (1989), working with soybeans (*Glycine max*), demonstrated the effects of different pollutants on morphology and spectral

reflectance. Plants receiving exposure to arsenic showed a spectral change in the chlorophyll absorption band centered at 680 nm, the 'red edge.' At the long-wavelength edge of this band, a shift occurred in the spectral signature to shorter wavelengths. Higher reflectance was also observed in the 550-650 nm region. However, plants treated with selenium showed an opposite effect. The spectral signatures of selenium-treated plants displayed a shift to longer wavelengths of the red edge, and had a lower reflectance between 550 nm and 650 nm. In addition to spectral reflectance changes, the plants displayed morphological changes. Plants exposed to arsenic, compared to control plants, had roots that were small and discolored, lower plant biomass, and smaller leaves that were oriented more vertically than those of the control. Plants exposed to selenium also experienced morphological changes, but they were less pronounced than the arsenic-dosed plants. Therefore, while arsenic and selenium are not directly observable from an aerial or satellite platform, it is possible to observe their effects on vegetation by monitoring for detectable signs of stress. Figure 4 shows the morphological effects that selenium and arsenic can have on soybean plants.

Other stress agents may have effects on spectral reflectance similar to those of arsenic and selenium. Verification in the field of the exact identity of the agent is important not only for verifying the measurements acquired through remote sensing, but also to determine the cause for observed deviations from the norm (i.e. the 'average' or expected spectral signature of a given ecosystem). The change in spectral reflectance may not be unique for a particular stress (Carter 1993). Pollutants such as herbicides and ozone may cause similar spectral changes. Responses to stress, such as senescence and dehydration, may also show similar spectral responses. Without field verification, it is possible to attribute a given spectral signature to the wrong stress.

In performing a study meant to identify pollution, it is recommended that one proceed as they would for vegetative stress. If deviations from expected values are observed in the spectral reflectance, ground studies need to be undertaken to determine the exact nature of the stress or pollutant.

Conclusion

Remote sensing is an excellent tool for detecting signs of vegetation stress and pollution. However, it does have limitations that scientists and managers need to be aware of. Many signs of stress create spectral changes in vegetation, and seasonal changes in the spectral reflectance of plants always occur. If stress is detected in the spectral reflectance of a plant, fieldwork on the ground is required to determine the exact nature of the stress or pollutant. Remote sensing can save time and effort in performing initial surveys or monitoring studies, and can, depending on the resolution and type of equipment used, be an effective way of conducting a study with results better or as good as more traditional techniques. In time, remote sensing will move much more into the mainstream as a tool that can be used for wetlands analysis.

Note: CERSP maintains a database on the functional comparison of created and natural wetlands at <http://www.vims.edu/rmap/cers/>

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